(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 267 050 A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 87309854.5

(22) Date of filing: 06.11.87

(51) Int. Cl.⁴: A 61 K 9/50
A 61 K 9/12

(30) Priority: 06.11.86 US 927898

(43) Date of publication of application:
11.05.88 Bulletin 88/19

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI LU NL SE

(71) Applicant: Clayton Foundation for Research
Three Riverway Suite 1625
Houston Texas 77056 (US)

(72) Inventor: Knight, Jack Vernon
11735 Green Bay Drive
Houston Texas 77024 (US)

Gilbert, Brian E.
5171 Jason
Houston Texas 77096 (US)

Wilson, Samuel Z.
4328 Briarbend
Houston Texas 77035 (US)

Six, Howard R.
5138 Karenbeth
Houston Texas 77084 (US)

Wyde, Philip R.
11002 Braewick
Houston Texas 77096 (US)

(74) Representative: Wilkinson, Stephen John et al
c/o Stevens, Hewlett & Perkins 5 Quality Court Chancery Lane
London WC2A 1HZ (GB)

(54) Small particle aerosol liposome and liposome-drug combinations for medical use.

(57) Disclosed are small particle aerosol liposome and liposome-drug combinations advantageous for the treatment of a wide variety of diseases. Different methods of preparation of liposome and liposome-drug combinations are described which can be used in small particle aerosol treatment.

EP 0 267 050 A2

Attorney Docket No.: 11390-005-999
Serial No.: 09/701,450
Reference: B05

Bundesdruckerei Berlin

Description

Small Particle Aerosol Liposome and Liposome-Drug Combinations for Medical Use

Field of the Invention

The field of the invention is small particle aerosol liposomes and liposome-drug combinations advantageous for medical use.

Background of the Invention

Small particle aerosol is defined as a colloid system in which the continuous phase is a gas, and the majority of particles are less than 5 microns in diameter with an aerodynamic mass median diameter ranging from 1 to 3 microns. The advantage of such a discretely sized population of particles is that, because of their small size and low settling velocities, they will penetrate when inhaled into the lower respiratory tract in substantial percentages. For example, 1.5 micron particles will deposit 46 percent of the total inhaled in the lung and another 36 percent in nose and upper air passages. Such uniform deposition will permit treatment of lesions at any level of the respiratory tract (Gilbert, B. E., Wilson, S. Z., and Knight, V., 1986, Ribavirin Aerosol Treatment of Influenza Virus Infections. In: Options for the Control of Influenza. UCLA Symposium on Molecular and Cellular Biology. Alan R. Liss, Inc., New York, New York, p. 343.)

Small particle aerosol treatment delivers a high dose of drug to the epithelium of the respiratory tract in amounts largely unachievable by other routes of administration (Knight, V. 1973, Airborne Transmission and Pulmonary Deposition of Respiratory Viruses. In: Viral and Mycoplasmal Infections of the Respiratory Tract. V. Knight, ed. Lea and Febiger, Philadelphia, Pennsylvania, p. 1). There is a subsequent steady rate of absorption of drug into the systemic circulation.

Dried phospholipids placed into an aqueous environment will spontaneously associate into multilamellar structures that function as permeability barriers. These lipid vesicles, termed liposomes, are composed of aqueous compartments separated from each other and the external medium by a series of closed concentric lipid bilayers. The composition of the aqueous compartments is the same as the medium in which the liposomes were formed; this makes it possible to entrap a wide variety of materials within the lipid bilayers. Entrapped markers can be released by a variety of lytic agents in a manner analogous to natural membranes. Since liposomes may be prepared from substances found in normal cell membranes, they are perceived as nontoxic to mammalian host; and recent studies in humans and laboratory animals have supported this concept.

The ability to encapsulate water soluble compounds in liposomes led to speculation that they might be useful clinically as carriers of drugs. This expectation has not been fully realized for water soluble drugs. However, recent studies with water insoluble anticancer and antimicrobial compounds have suggested that liposomes may be ideally suited for delivery of this type of drug. The amounts of drug associated with liposomes are high, and release does not occur until the membranes are destroyed either by mechanical means or by biodegradation, thus allowing a more controlled release of the drug over time. Moreover, in laboratory animals the use of liposomes actually reduced toxic effects observed with the drug alone.

Liposome-drug compounds are heterogeneous in size ranging from less than 1 micron up to 10 microns in diameter and have been given in relatively large oral or intravenous doses.

Description of the Prior Art

Applicants are unaware of any prior art disclosing, suggesting, or teaching small particle aerosol liposomes and liposome-drug combinations for medical use or that the heterogeneous size of small liposomes and liposome-drug combinations can be reduced to a more homogeneous population of small liposome particles (<1 micron in diameter). The size of the aerosol particle is controlled by the operating characteristics of the aerosol generator or nebulizer without any loss in effectiveness thereof. One to several liposomes or liposome-drug particles (<1 micron in diameter) may be contained in a single aerosol droplet (1-3 micron, aerodynamic mass median diameter) depending on the concentration of liposome material in the preparation that is to be nebulized.

Liposomes are effective carriers for the introduction of various agents into cells in in vitro experiments. A large number of scientific papers have been published describing liposomes as carriers for both water-soluble and lipid-soluble agents. Several hundred different substances have been entrapped in liposomes. For a further description of liposomes, their preparation and application, reference is made to American Laboratory, pages 125-135, October, 1985.

The following articles and patents are representative of the prior art:

AMA Drug Evaluation, 5th Edition, pp. 1162-1166

Annals NYAS, "Liposomes in Therapeutic and Preventive Medicine: The Development of the Drug-Carrier Concept", G. Gregoriadis, 1978, 308:343-65

Clinical Science and Mol. Med., "Tissue and Hepatic Subcellular Distribution of Liposomes Containing Bleomycin after Intravenous Administration to Patients with Neoplasms", A. W. Segal, G. Gregoriadis, J. P. Lavender, D. Tarin, T. J. Peters, 1976, 51:421-25

J. Infect. Dis., "Liposomal Amphotericin B for the Treatment of Systemic Fungal Infections in Patients with

Cancer: A Preliminary Study", G. Berenstein-Lopez, V. Fainstein, R. Hopfer, K. Mehta, M. Sullivan, M. Keating, M. Rosenblum, R. Mehta, M. Luna, E. Hersh, J. Reuben, R. Juliano, G. Bodey, 1985, 151:704-10
Infect. Immun., "Effect of Liposomal Amphotericin B on Murine Macrophages and Lymphocytes", R. Mehta, K. Mehta, G. Lopez-Berenstein, R. Juliano, 1985, 47:429-33
The Lancet, "Artificial Surfactant Therapy in Hyaline-Membrane Disease", T. Fujiawara, H. Maeta, S. Chida, T. Morita, Y. Watabe, T. Abe, 1980, 1:55-59
Pediatrics, "Hyaline Membrane Disease Treated with Bovine Surfactant", J. A. Smyth, I. L. Metcalfe, P. Duffty, F. Possmayer, M. H. Bryan, G. Enhorning, 1983, 71:913-17
Pediatrics, "Isolation of Human Surfactant from Amniotic Fluid and a Pilot Study of its Efficacy in Respiratory Distress Syndrome", M. Hallman, T. A. Merritt, H. Schneider, B. Epstein, F. Mannino, D. Edwards, L. Gluck, 1983, 71:473-82
Pediatric Res., "Nebulization of Sonicated Phospholipids for Treatment of Respiratory Distress Syndrome of Infancy", H. H. Ivey, J. Kattinwinkel, S. Roth, 1977, 11:301-14
The Lancet, "Dry Artificial Lung Surfactant and its Effect on Very Premature Babies", C. J. Morley, A. D. Banham, N. Miller, J. A. Davis, 1981 1:64-68
The Lancet, "Controlled Trial of Artificial Surfactant to Prevent Respiratory Distress Syndrome", H. L. Halliday, G. McClure, M. Reid, T. R. J. Lappin, C. Meban, P. S. Thomas, 1984, 1:476-78
U.S. Patent No. 4,370,349 disclosing a process for preparing a freeze-dried, potential liposome mixture
U.S. Patent No. 3,873,720 disclosing an aqueous mixture of fat, carbohydrate and amino acids emulsified with the aid of long chain fatty acid or its basic amino acid salts and egg-yolk phospholipds.
U.S. Patent No. 4,073,943 disclosing parenteral administration of water-insoluble pharmacologically active agents in lipoyd phase.
U.S. Patent No. 4,168,308 disclosing parenteral administration of water-insoluble pharmacologically active agents in lipoyd phase.
U.S. Patent No. 4,536,519 directed to an emulsifying agent and emulsified cosmetics
U.S. Patent No. 4,563,354 disclosing parenteral administration of oil and water emulsions

Summary of the Invention

The present invention is directed to small particle aerosol liposomes and liposome-drug combinations having advantageous properties for medical use. Small particle aerosol, as used herein, is a colloid system in which the continuous phase is a gas, and the majority of particles (i.e. more than 50% of the total number of particles) are less than 5 microns in diameter with an aerodynamic mass median diameter ranging from 1 to 3 microns. The liposomes are heterogeneous in size ranging from less than 1 micron up to 10 microns in diameter. Advantageously, the particle size of the liposomes and the liposome-drug compositions are processed by the aerosol nebulizer to sizes of less than one micron diamter; and these smaller liposome and liposome-drug particle retain their pharmacological activity.

Small particle aerosol treatment by liposomes alone is advantageous since liposomes can closely mimic pulmonary surfactant and may repair defects in this system that have developed for a variety of reasons.

The drugs to be given by liposome-drug combinations range widely as does the dosage. In general, the drugs in recommended dosages for non-aerosol liposome-drug combinations of the prior art can be used for the small particle aerosol liposome drug-combinations without the disadvantages of the prior art liposome-drug combinations. The amount of the drug in the liposome-drug combination aerosol is controlled by the concentration of drug in the reservoir of the aerosol generator. Also, the amount of drug employed depends on the duration of treatment, drug used and the like. For example, dosage for 24 hours can range from less than a nanogram to a few grams depending on need, toxicity, biological and chemical properties of the drug, and other factors. Liposome-drug combinations can include both aqueous and lipid soluble drugs.

Accordingly, it is an object of the present invention to provide small particle aerosol containing liposomes or liposome-drug combinations for medical use.

A further object of the present invention is the provision of a method of processing liposomes by the aerosol nebulizer from heterogeneous sizes to substantially uniform small particle liposomes (<1 micron in diameter) without loss of effectiveness.

A still further object of the present invention is the provision of a method of processing liposome-drug combinations in which the liposomes form heterogeneous sizes to substantially uniform, small particles of liposome-drug combinations without any loss of effectiveness.

A further object of the present invention is the provision of treating a patient with liposomes by delivering small particle aerosol liposomes to the epithelium of the respiratory tract.

A still further object of the present invention is the provision of treating a patient by delivering small particle aerosol liposome-drug combinations to the epithelium of the respiratory tract.

A further object of the present invention is the provision of liposome-drug combinations in which a wide variety of drug combinations for a wide variety of disease can be administered effectively to the patient.

Other and further objects, features, and advantages of the present invention appear throughout and are inherent therein.

Description of Presently Preferred Embodiments

As previously set forth, the present invention is directed to small particle aerosol liposomes and liposome-drug combinations, to methods of generating aerosols of them, and to methods of treating patients with them. As the term "small particle aerosol" is used herein, it is defined as a colloid system in which the continuous phase is a gas, and the majority of particles are less than 5 microns in diameter with an aerodynamic mass median diameter ranging from 1 to 3 microns. Liposome-drug combinations of the prior art are heterogeneous in size ranging from less than 1 micron up to 10 microns in diameter and, have been given to patients in relatively large oral or intravenous doses. Such dosage results in high and potentially toxic plasma concentrations of drugs, but low concentrations on the respiratory epithelium. Unexpectedly, the heterogeneous lipsomes and the liposome-drug combinations can readily be converted to a more homogeneous small size by an aerosol nebulizer without any loss in effectiveness of the liposomes and liposome-drug combinations. Any type of aerosol nebulizer can be used which so reduces the size of the liposome. Examples of nebulizers that can be used include Puritan Bennett Models Nos. 1920 and 1917 which are both commercially available. Advantageously, the small particle aerosol liposomes and liposome-drug combinations, when inhaled, provide a high concentration on the respiratory epithelium and a steady rate of absorption into the circulation without the hazard of peak levels that may be associated with large oral or intravenous doses of drug, and deliver a high dose of drug to the epithelium of the respiratory tract in amounts largely unachievable by other routes of administration. As previously mentioned, the advantage of such a discretely sized population of particles is that, because of their small size and low settling velocities, they will penetrate when inhaled into the lower respiratory tract in substantial percentages. For example, 1.5 micron particles will deposit 46% of the total inhaled in the lung and another 36% in the nose and upper air passages. Such uniform deposition permits treatment of lesions at any level of the respiratory tract and also provides an interface into the cell without the problems and disadvantages associated with oral and intravenous injections.

The following Table 1 sets forth representative examples of water and lipid soluble drugs that may be administered in liposome small particle aerosols.

Table 1

Antiasthma

metaproterenol
aminophylline
theophylline
terbutaline
Tegretol
ephedrine
isoproterenol
adrenalin
norepinephrine

Antiarrhythimic

propanolol
atenolol
verapamil
captopril
isosorbide

Tranquilizers

chlorpromazine
benzodiazepine
butyrophenones
hydroxyzines
meprobamate
phenothiazines
reserpine
thioxanthines

Cardiac glycosides

digitalis
digitoxin
lanatoside C
digoxin

Hormones

antidiuretic
corticosteroids
testosterone
estrogen
thyroid
growth
ACTH
progesterone
gonadotropin
mineralocorticoid

Steroids

prednisone
triamcinolone
hydrocortisone
dexamethasone
betamethosone
prednisolone

Antihypertensives

apresoline
atenolol

Antidiabetic

Diabenese
insulin

Antihistamines

pyribenzamine
chlorpheniramine
diphenhydramine

Antiparasitic

praziquantel
metronidazole
pentamidine

Anticancer

azathioprine
bleomycin
byclophosphamide
adriamycin
daunorubicin
vincristine

Sedatives & Analgesic

morphine
dilaudid
codeine
codeine-like synthetics
demerol
oxymorphone
phenobarbital
barbiturates

Antibiotic

penicillin
tetracycline
erythromycin
cephalothin
imipenem
cefofaxime
carbenicillin
vancomycin
gentamycin
tobramycin
piperacillin
moxalactam
amoxicillin
ampicillin
cefazolin
cefadroxil
cefoxitin
other aminoglycosides

Immunotherapies

interferon
interleukin-2
monoclonal antibodies
gammaglobulin

Antifungal

amphotericin B
myconazole
muramyl dipeptide
clotrimazole

Antihypotension

dopamine
dextroamphetamine

Vaccines

influenza
respiratory syncytial virus
Hemophilus influenza vaccine

Antiviral

acyclovir and derivatives
Winthrop-51711
ribavirin
rimantadine/amantadine
azidothymidine & derivatives
adenine arabinoside
amidine-type protease inhibitors

Other

cell surface receptor blockers

Liposome Preparation

Liposomes and liposome-drug combinations may be prepared in any suitable manner, for example, as described in American Laboratory, pp. 125-135, October, 1985, and U.S. Patent No. 4,370,349, Evans, et. al., January 25, 1983. These publications amply document that a variety of amphipathic lipids are suitable for preparing of liposomes for use in this invention.

Suitable lipids include the phospholipids, for example the natural lecithins derived from egg-yolk or soya-bean, sphingomyelin derived from beef brain or synthetic lecithins, for example dimyristoyl-phosphatidylcholine, dipalmitoyl-phosphatidylcholine or distearoyl-phosphatidylcholine, or unsaturated synthetic lecithins, for example, dioleyl-phosphatidylcholine or dilinoleyl-phosphatidylcholine. Either a single phospholipid or a mixture of phospholipids may be used. Sterols, for example, cholesterol or ergosterol, may be added to increase stability of the liposomal bilayers and lipids possessing a positive or negative change, for example, phosphatidylethanolamine, beef brain ganglioside or phosphatidic acid, may be used to render the appropriate charge to the liposome and to increase the size of the aqueous compartments. Mixtures of lipids may be used to render the liposomes more fluid or more rigid and to increase or decrease permeability characteristics.

Liposomes can be prepared by a variety of methods. These procedures have in common the dispersal of a phospholipid or mixture of lipids into a suitable container and the removal of an organic solvent, for example, ether, chloroform, or T-butanol, by methods such as evaporation, rotary evaporation under vacuum or lyophilization with commercially available freeze-drying equipment. Dispersing the resulting lipid film or dry lipid powder in an aqueous medium for example, distilled water, isotonic saline or buffered solutions will result in the formation of liposomes. For example, phosphatidylcholine is dissolved in re-distilled T-butanol and transferred to a bottle. The solution is frozen and the solvent is removed under vacuum using a commercial freeze-dryer. Sterile pyrogen-free distilled water is added to the freeze dried powder and the bottle shaken to disperse the powder. The resulting milky suspension can be examined microscopically and the suspension shown to contain liposomes that are heterogenous in size ranging from less than 1 micron up to 10 microns.

Any biologically active compound may be associated with liposomes. Whether the compound is associated with the lipid portion of the liposomes or resides in the aqueous compartments is dependent upon the physical and chemical properties of the compound of biological interest. It is understood that the procedures used for preparing liposome-drug combinations are not restricted under this invention, any procedure that results in liposomes would be applicable. For purposes of disclosure, three general methods of producing liposomes are described below. They illustrate that regardless of chemical and physical properties a wide array of biologically active compounds can be assoicated with liposomes and that such liposomes are applicable to delivery by small particle aerosol.

Method I may be used to incorporate lipid soluble or lipid-bound biologically active compounds. For example, egg lecithin (phosphatidylcholine) or similar phospholipids dissolved in an organic solvent is transferred to a suitable flask or bottle. The desired lipid soluble compound is added, the solution is frozen and the solvent is removed using a commercial freeze-dryer. Liposomes are formed by the addition of a suitable aqueous medium, for example, sterile distilled water, isotonic saline or a buffered solution followed by vigorous shaking of the container. It is recognized that the phospholipid or mixture of phospholipid used to prepare the liposomes can be altered to increase or decrease the lipid solubility of the active compound as desired and that solvents such as chloroform, n-butanol, t-butanol, or pyridine may be used to promote interaction of the compound and phospholipid. The specific procedure can be tailored to accommodate the individual properties of specific compounds.

Method II may be used to incorporate water soluble biologically active compounds. For example, egg lecithin dissolved in redistilled T-butanol is transferred to a suitable flask or bottle. The solution is frozen and the solvent is removed using a commercial freeze-dryer. Compounds to be entrapped in the liposomes are then added to the dry powder in aqueous medium and the liposomes are formed by vigorous shaking of the vessel to disperse the dry powder. Under these conditions, entrapment of 4-5% of the water soluble compound is expected but addition of a sterol and/or a charged amphiphile in the lipid mixture can increase the entrapment efficiency up to approximately 30%. A dry compound that remains "free" in the external medium can be separated by a variety of procedures, for example centrifugation, molecular sieve chromatography or dialysis. The desirability of removing the free compound or not is dependent upon the intended medical use, the biologic activity of the compound, the desired dose and the quantities incorporated into the liposomes.

Method III may be used to incorporate biologically active compounds without regard to their solubility characteristics. In this procedure the compound is covalently attached to a lipid with the result that the lipid moiety will associate with the liposome and anchor the compound to the liposomal bilayers. Phosphatidylethanolamine and palmitic acid have been utilized for this purpose but a variety of lipids may be applicable to this method. In this procedure the compound and a lipid derivative capable of derivatizing the compound, for example, the N-hydroxy-succinimide ester of palmitic acid, N-succinyl-phosphatidylethanolamine, or alternatively phosphatidylethanolamine in the presence of a dehydrating agent such as N- N'-dicyclohexylcarbodiimide, are mixed in a suitable solvent and allowed to react. The lipid derivative of the compound is then purified and incorporated into liposomes. For example, egg lecithin or similar phospholipid and appropriate quantities of lipid derivatized compound are dissolved in an organic solvent and added to a suitable flask or bottle. The solution is frozen and the solvent removed in a freeze-dry apparatus. Liposomes then formed by

addition of suitable aqueous medium to the dry powder, followed by vigorous shaking of the container. It is recognized that wide variety of chemical reactions can be utilized to prepare lipid derivatives of biologically active compounds and that alternative procedures will be suitable, if the resulting derivative can be associated with liposomes and if the biological activity of the compound has not been irreversibly destroyed by the process. It is also recognized that lipid derivatives of some compounds, for example peptides, proteins or hormones may be efficiently incorporated when added in the aqueous medium rather than to the organic solvent.

Liposome-Drug Combination

Example 1

One aspect of the invention, and the present example are directed to liposome-drug combinations where the drug is enviroxime and made according to Method I.

For enviroxime containing liposomes, phosphatidylcholine (450 mg) was added to a 500 mL flask in chloroform (30 mL) and 120 mg of enviroxime was added to the solution. The solvent was removed under vacuum and the lipid-drug mixture dissolved in 60 mL of T-butanol. The solution was frozen and the solvent removed in a commercial freeze-dry apparatus. Liposomes were prepared by mechanically shaking the dried residue in 30 mL of sterile water. Liposomes prepared by this procedure were examined microscopically and they were found to be heterogeneous in size ranging from less than 1 micron up to 10 microns in diameter. The preparation was then placed in a small particle aerosol generator that used a Collison nebulizer for formation of the small particles. During passage through the nebulizer, the liposomes were reduced in size so that most liposomes were less than 1 micron in diameter and many less than 0.1 microns in diameter. The size of the particles containing enviroxime-liposomes delivered to the patient is controlled by the operational characteristics of the aerosol generator. The majority of these particles were less than 5 microns in diameter with an aerodynamic mass median diameter ranging from about 1 to 3 microns. Any type of aerosol nebulizer can be used which so reduces the size of the liposome, a number of which are available on the market. For example, Puritan Bennett nebulizer model No. 1920 or model No. 1917 can be used by placing the liposomes or liposome-drug combinations in the reservoirs of these nebulizers. Accordingly, no further description of the nebulizers is deemed necessary or given.

We have found that the enviroxime-containing liposomes as initially made (as present in the aerosol reservoir at the start of operation of the aerosol generator) are very heterogeneous in size, ranging from 0.7 microns down to less than 0.03 microns in diameter. Following processing by the small particle aerosol generator (SPAG), observations of the liposomes in the aerosol reservoir after 60 minutes of operation and also of liposomes in an aerosol sample collected in an All Glass Impinger (AGI) after 15 minutes of operation show that the liposomes become more homogeneous in size, with the larger ones being less than about 0.35 microns in diameter. The generation of small particle size does not change the structure of the liposomes and the liposomes were found to have retained their liposome characteristics and to be multi-lamellar liposomes of "classical" structure.

Enviroxime is a substituted imidazole with exceptional potency against all rhinoviruses tested: inhibitory concentrations generally range from 0.3 to 0.9 µg/mL. Maximum tolerated concentrations for cells in culture range from 4 to 100 µg/mL, resulting in therapeutic ratios ranging from 50 to 100. Enviroxime is active also against polioviruses, echoviruses and coxsackieviruses. The drug was discovered by Eli Lilly and Company.

Enviroxime is only slightly soluble in water (1-2 µg/mL) and this has posed a problem in medical use of the drug. This difficulty is overcome by preparing liposomes of enviroxime (1-8 mg/mL) and phosphatidylcholine (15 mg/mL) in particles small enough to be administered as a small particle aerosol. By this methodology, doses of 6 to 12 mg/hr can be given to the respiratory tract.

Treatment periods of one hour to four hours per day are satisfactory. Daily dosage is set forth in Table 2 for an average sized adult (70 kg):

Table 2

Duration	Mg/Hr	Total Dose (mg)	Mg/Kg/Day
1 hr	6	6	0.08
1 hr	12	12	0.16
2 hr	6	12	0.16
2 hr	12	24	0.32
4 hr	6	24	0.32
4 hr	12	48	0.64

Table 2 reveals that all proposed doses are substantially less than 1 mg/kg/day. Tolerance studies in animals summarized below show lack of untoward effects with doses many-fold larger than those proposed above.

Animal Tolerance Studies: Pharmacokinetics

Effects in vitro on muscle. Muscle from many organs of rats was tested in 10^{-5} to 10^{-8}M enviroxime. It did not activate adrenergic, histamine, prostaglandin E2 and a number of other biological receptors. There was some non-competitive antagonism of dose response curves similar to that of potassium chloride.

Effects on electrolytes. At dose of 25 mg/kg and above there was significant oliguria in rats. The oliguria was associated with increases in potassium in serum but not sodium.

Effects in mice. Doses of 50 mg/kg orally produced no detectable effects. At higher doses, 100-400 mg/kg, there was increasing leg weakness, decreased motor activity and gait disturbances. The effect of high doses was rapid, occurring within a few minutes. A number of other tests were performed with oral doses and in general doses up to 100 mg/kg were well tolerated. Of particular interest was the finding that there was no immune suppressive activity of enviroxime on primary antibody response in mice.

Effects on cats and dogs. There was no significant cardiovascular effects on cats. There was some stepwise depression of diastolic blood pressure in dogs following 1, 3, and 10 mg/kg I.V. doses. Plasma concentrations of enviroxime were 3.0, 8.9 and 19 µg/mL following these I.V. doses. Bioassay (antiviral) and biochemical assay of blood yielded similar results.

The above studies, and others, are acceptable as evidence of adequate safety for human use and human studies

Example 2

In this aspect of the invention and example ribavirin is the drug in the liposome-drug combination which is made by Method II.

For ribavirin containing liposomes, 450 mg of egg phosphatidylcholine was added to a 500 mL round bottom flask and the organic solvent removed under vacuum. Ribavirin (600 mg) in 30 mL of aqueous medium (sterile phosphate buffered saline) was added and the liposome prepared by mechanical shaking. Again, the ribavirin-liposomes were heterogeneous in size but passage through a Collision nebulizer reduced the ribavirin-liposomes to sizes as set forth in Example 1.

Example 3

In this aspect of the invention and example, Method III, methotrexate is the drug in the liposome-drug combination. (Hashimoto, K., Loader, J. E., and Kinsky, S. C., 1985, Synthesis and Characterization of Methotrexate-dimyristoylphosphatidylethanolamine Derivatives and the Glycerophosphorylethanolamine Analogs. Biochim. Biophys. Acta 816:163-168; Hashimoto, K., Loader, J. E., Knight, M. S., and Kinsky, S. C, 1985, Inhibition of Cell Proliferation and Dihydrofolate Reductase by Liposomes Containing Methotrexate-dimyristoylphosphatidylethanolamine Derivates and by the Glycerophosphorylethanolamine Analogs. Biochim. Biophys. Acta 816:169-178).

Methotrexate (40 µmol) is dissolved in 0.8 mL of a 1:1 volume mixture of chloroform and methanol (hereafter abbreviated C/M) containing triethylamine (240 µmol). The following were then added sequentially to this solution while stirring; dimyristoyl-phosphatidylethanolamine (120 µmol) dissolved in 5.6 mL of C/M; N-hydroxysuccinimide (200 µmol) dissolved in 0.8 mL of C/M; N,N'-dicyclohexylcarbodiimide (200 µmol) dissolved in 0.8 mL of C/M. After incubation for 3 hours at room temperature, the reaction mixture was taken to dryness by rotary evaporation under reduced pressure at 40°C, and the residue was redissolved in 2 mL of C/M.

Chromatographic separation of the methotrexate phosphatidylethanolamine derivatives was accomplished by streaking 250 µL of this fraction on each of 8 analytical thin-layer plates (Silica gel 60 F-254, 0.25 mm,

Brinkmann Instruments, Inc., Westbury, New York). The plates were developed in a solvent system of chloroform/methanol/water (65:30:5 by vol.). After development, four yellow bands (I-IV) were visible that also gave a positive test for phosphate when sprayed with an acid molybdate reagent (Applied Science, Deerfield, Illinois). These bands had approximate R_F values of 0.18 (I), 0.28 (II), 0.39 (III), and 0.49 (IV), whereas the R_F for the unreacted methotrexate band, which did not stain for phosphate was 0.06. Band I which was shown to possess full biologic activity was scraped from the plates and suspended in 5 mL of methanol. After centrifugation (750 x g for 10 min. at 4°C), the yellow supernatant was recovered, and the pelleted silica gel particles were reextracted with another 5 mL of methanol. Ten mL of chloroform was added to the combined supernatants, and this solution was layered over a 50 mm high bed of Unisil (Clarkson Chemical Co., Williamsport, Pennsylvania) at the bottom of a 1 x 20 cm column. The Unisil previously had been washed extensively with chloroform, followed by C/M. The yellow compound (designated MTX-CMPE) was subsequently eluted by passage of 20 mL of C/M. The eluate was taken to dryness, and the residue was redissolved in 5 mL of C/M and stored at -20°C.

Liposomes were generated from dried lipid films containing dioleoyl-phosphatidylcholine (DOPC), cholesterol, and dicetylphosphate in a molar ratio of 2:1.5:0.2, respectively. The film was also supplemented with 2.5 mol% of MTX-DMPE I on the basis of phosphate content. The lipid films were dispersed by vortexing in sufficient balanced salt solution to give a 10 mM liposomal (DOPC) suspension. MTX-DMPE I had a phosphate methotrexate ratio of 1. Accordingly, the final methotrexate density in liposomes prepared with the derivative was 2.5 mol% methotrexate.

Further examples, numbered 4 to 23 are shown in Table 3 in which the preferred methodology for preparation in liposomes, concentration of drug in the aerosol reservoir and the amount of drug delivered in aerosol in a specified period of time are shown. The delivered doses approximate single doses of drug which might be given by oral or parenteral routes of administration.

Table 3

Suggested Delivered Dose of Representative Liposome-Containing Compounds as Delivered by Small Particle Aerosol

Example No.	Compound	Method[1]	Concentration in Reservoir (mg/mL)	Duration of Treatment	Estimated Delivered Dose[2] (mg)
4	Amantadine	1	4	12 hrs	172
5	Digtoxin	1	1	20 min	1
6	Isosorbide	1	0.5	3 hrs	5
7	Estrogens	1	0.8	8 hrs	23
8	Diabinese	1	6	10 hrs	216
9	Amphotericin B	1	20	30 min	36
10	Prednisone	1	8	60 min	29
11	Interferon	1	$5x10^6$ units/mL	20 min	$6x10^6$ units
12	Isoproterenol	2	2	20 min	2
13	Apresoline	2	15	20 min	18
14	Gentamycin	2	100	30 min	180
15	Propanolol	2	3	20 min	4
16	Dopamine	2	150	20 min	180
17	Chlorpromazine	2	60	20 min	72
18	Diphenhydramine	2	15	20 min	18
19	Morphine sulfate	2	10	20 min	12
20	Demerol	2	75	20 min	90
21	Acyclovir	2	20	12 hrs	864
22	Amantadine	2	20	12 hrs	864
23	Influenza vaccine	3	40 ug HA/mL	20 min	48 ug HA

1. Methods: 1) As per Method I for water insoluble compounds;
   2) As per Method II for water soluble compounds;
   3) As per Method III for covalent attachment of compounds to the surface of the lipid bilayer.

2. Estimated dose based on a 60% of maximum efficiency of aerosol generation and a 10 L minute minute volume for a 70 kg adult, and on currently given dosages.

Also, combinations of more than one drug can be combined with small particle liposome aerosols.

Advantageously, small particle aerosol treatment with liposome-drug combinations leads to deposition of drug and liposomes throughout the respiratory tract in substantial concentrations that can treat infections that are localized to the respiratory tract. In the case of viruses, the infection is localized to respiratory epithelial cells. In the case of bacteria or fungi, the diseases will be contained in inflammatory exudates and alveoli and in other anatomical spaces in the lung and within tissues of the lung at various locations. Aerosolized liposome-drug will be deposited on these sites.

In the case of lung tumors or primary or secondary origin, the tumor masses would be the site of deposition of aerosol liposome-anti cancer drugs.

In the case of asthma, aerosolized liposome bronchodilator agents would be deposited throughout the bronchial tree at sustained levels for extended periods of time to provide optimum therapeutic effect.

In the case of psychiatrically useful drugs, hormones, or cardioactive agents, systemic absorption following aerosol liposome-drug administration would occur at an even rate without high peaks in plasma concentration, thus avoiding potential toxicity and prolonging therapeutic effect.

Aerosol liposomes alone may replace natural surfactants in the lung of victims of drowning, chemical inhalational poisoning, and in premature infants deficient in surfactant.

Influenza or other vaccines can be given conveniently in small particle aerosol liposomes deposited directly on immunoreactive cells in the lung to elicit locally protecting immune responses. Humoral antibody may also be so stimulated.

Incorporation of some toxic agents such as amphotericin B into liposomes in aerosolized form retards their absorption into cells of the respiratory tract and reduces the toxic effect of the toxic agents without reducing their therapeutic effect.

Also, incorporation of polypeptides, oligonucleotides, enzymes, or other compounds which might be

destroyed or inactivated by localized enzymes may be protected from this effect when incorporated in small particle aerosolized liposomes thus increasing their therapeutic effect.

Thus, while specific examples of a variety of small particle liposomes and liposome-drug combinations have been given for purposes of disclosure, the present invention is applicable to all drugs or combinations of drugs which can be incorporated in small particle liposome aerosols for a wide variety of disease. Also, as previously mentioned, the dosage of the small particle liposome-drug combinations vary widely depending on the drug, duration of treatment and the like.

Accordingly, the present invention is well suited and adapted to attain the ends and carry out the objects and has the advantages and features set forth as well as others inherent therein. While presently preferred embodiments, uses, and treatments of various disease have been given for the purpose of disclosure, changes therein, modifications thereto, and other uses and treatments of disease can be made which are within the spirit and scope of the invention as defined by the following claims.

Claims

1. An aerosol containing liposome particles,
the majority of the aerosol particles having a diameter less than 5 microns.

2. An aerosol according to claim 1, wherein the particles have an aerodynamic mass median diameter in the range of from 1 to 3 microns.

3. An aerosol according to either claim 1 or claim 2 including liposome particles containing one or more drugs.

4. An aerosol according to claim 3 where the drug is selected from the group consisting of antiasthma, antiarrhythimic, antifungals, antihypertensives, anticancer, antibiotics, antidiabetics, antihistamines, antiparasitics, antivirals, cardiac glycosides, hormones, immunotherapies, antihypotensives, steroids, sedatives, and analgesics, tranquilizers, vaccines, and cell surface receptor blockers.

5. A method of generating the aerosol of Claims 1 or 2, comprising,
nebulizing heterogeneous particles of liposomes by a nebulizer effective to produce the aerosol particles of Claims 1 or 2.

6. A method of generating the aerosol of Claims 3 or 4 comprising,
nebulizing a heterogeneous liposome-drug combination with a nebulizer effective to produce the aerosol particles of Claims 3 or 4.

7. An aerosol container having a reservoir containing the liposome particles of Claims 1 or 2, and
having aerosol generating means in fluid communication with the reservoir effective to produce the aerosol of Claims 1 or 2, respectively.

8. An aerosol container having a reservoir containing the liposome particles containing the one or more drugs of Claims 3 or 4, and
having aerosol generating means in fluid communication with the reservoir effective to produce the aerosol of Claims 3 or 4, respectively.

9. A method of producing the aerosol composition of Claims 1 or 2, comprising,
placing the heterogeneous particles of liposomes in an aerosol reservoir, and aerosolizing the heterogeneous particles of liposomes.

10. A method of producing the aerosol composition of Claims 3 or 4, comprising,
placing the heterogeneous particles of liposomes containing one or more drugs in an aerosol reservoir, and
aerosolizing the heterogeneous particles containing the one or more drugs.